Cryospheric changes and uncertainties

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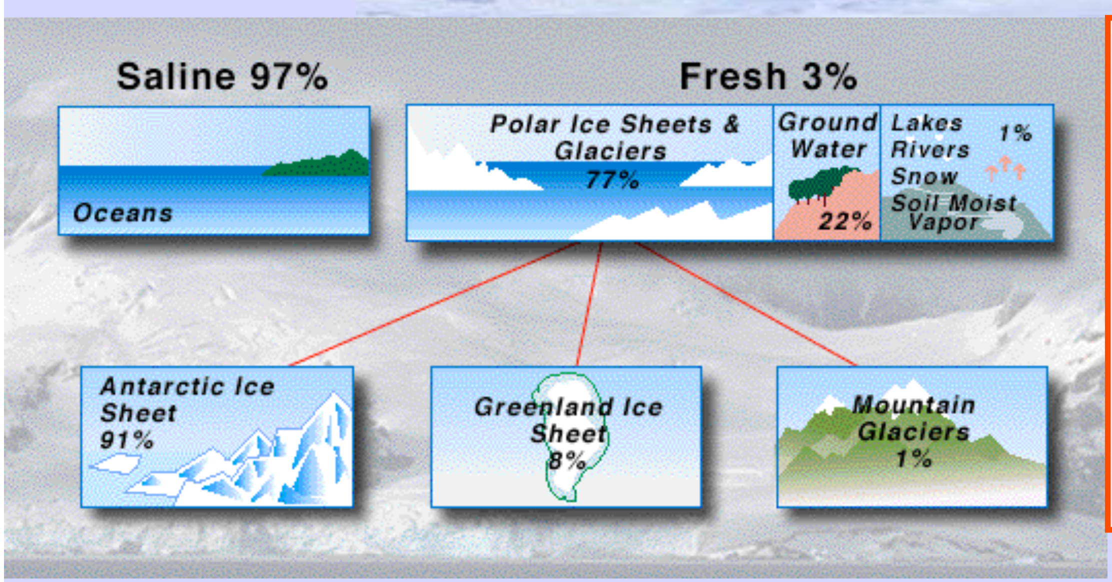
Where are the world's glaciers?



Global sea level equivalent

Greenland ~ 7 meters

West Antarctica ~5 meters

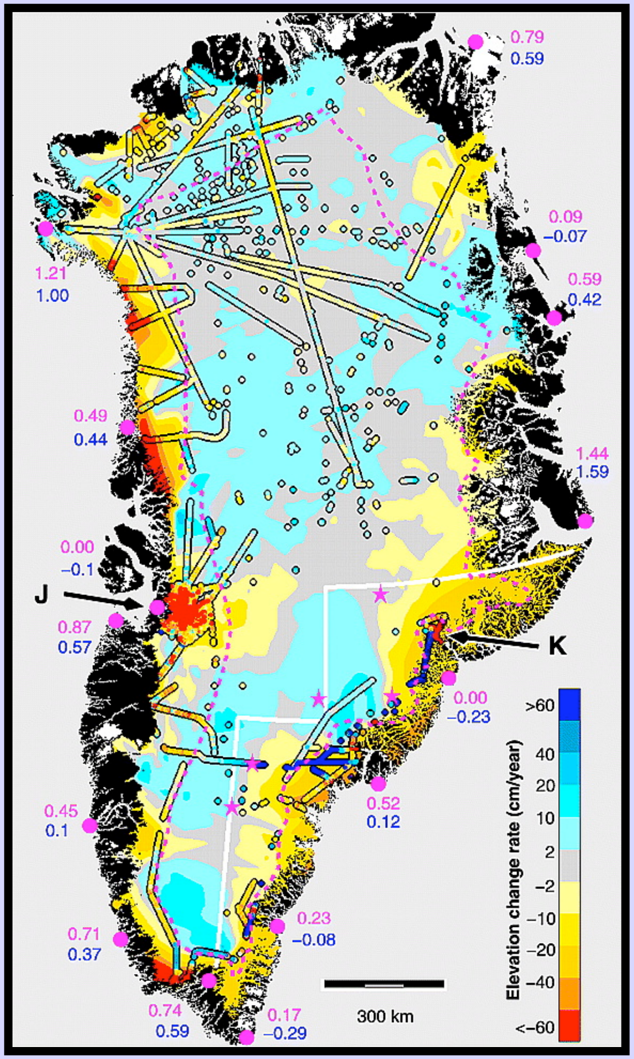
East Antarctica ~ 55 meters

Mountain glaciers ~0.5 meters.

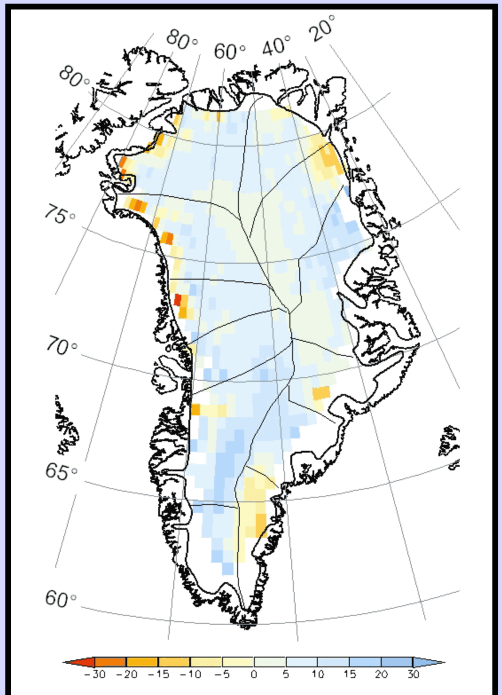
(Thermal expansion ~ 0.5 meters)

Ice sheets' annual turnover is 6 mm/yr vs sea level rise of 3 mm/yr

Greenland Ice Sheet Changes

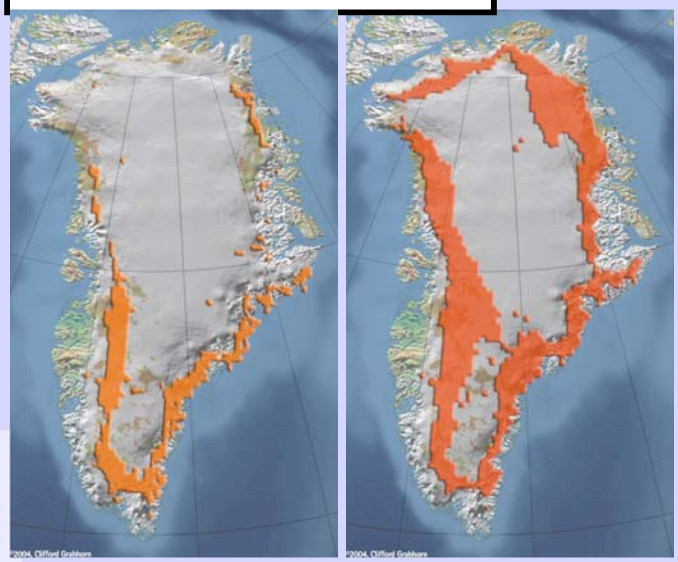


But more loss overall ..
(Krabill et al., 2004)



More snowfall ....
(Johannessen et al., 2005)

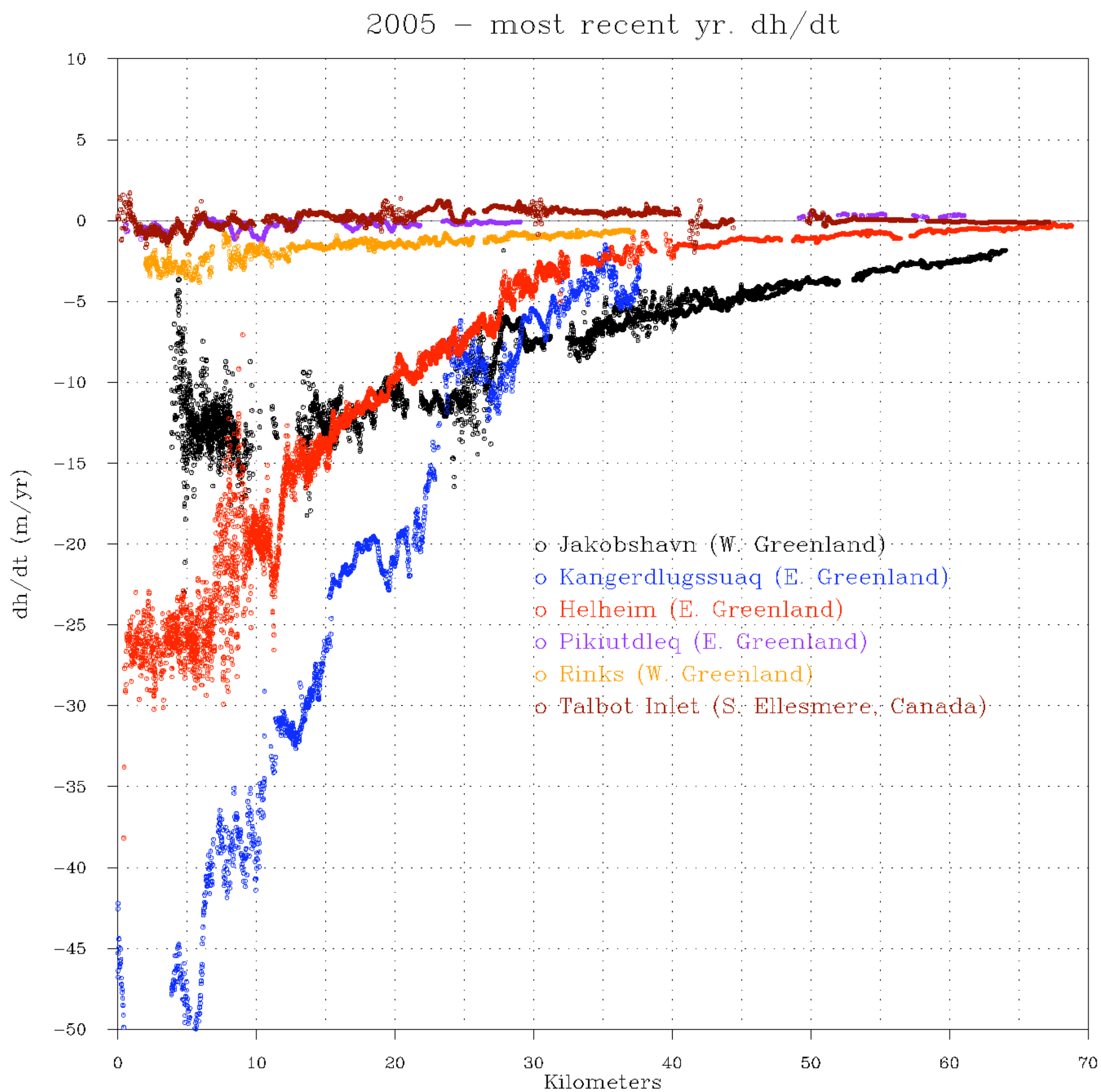
Accumulation 575 km^3/yr



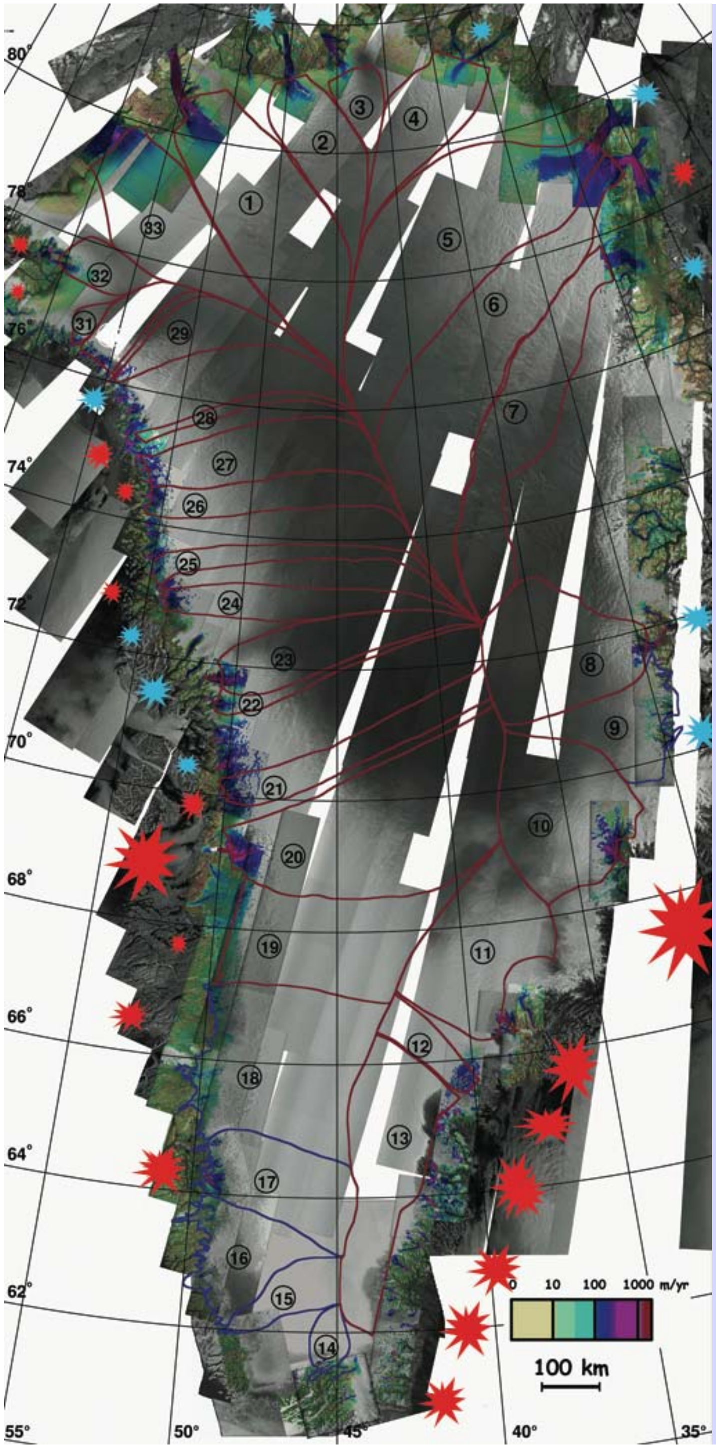
Melt 1992 Melt 2002

More melt ....
(Steffen et al., 2003)

Ice thinning from airborne laser altimetry



Krabill et al., 2006



Glacier speedup 1996-2006

First order acceleration:

Southeast glaciers: 150 to 250%
Central west: Jakobshavn Isbrae 200%
Sermia Kujatdleq 70°N (66%)
Igdluglip 74.5°N (70%) + unnamed (200%)
Southwest: Narssap Glacier 64.5°N (150%)

Second order acceleration:

Central west: Steenstrup (40%) 75° N
Upernavik (45%) 73° N
Southwest: Kangiata-nunata (38%) 64° N
Northwest: Tracy/Heilprin (36% and 15%) 77.5° N

Third-order acceleration:

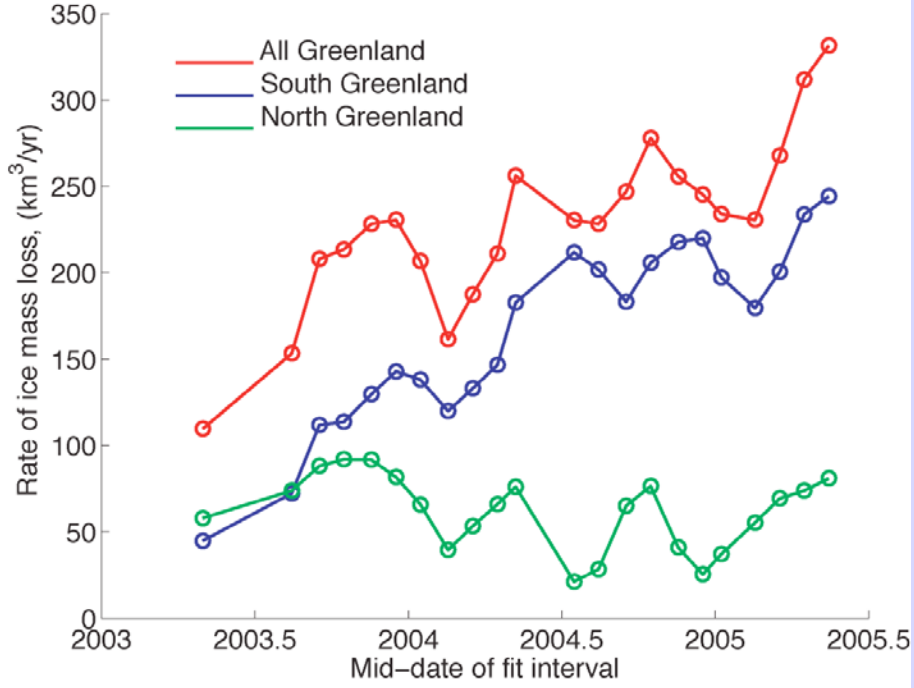
Southwest glaciers (22%) 66° N - 68.5° N
Northeast ice stream (18%) 79° N

Stable flow:

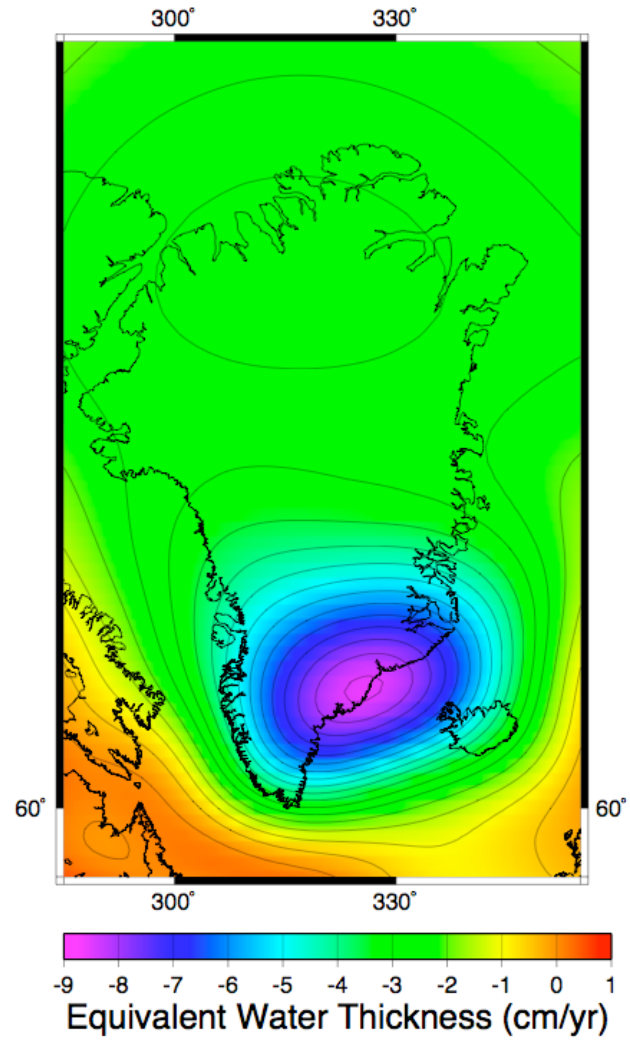
North and northeast: Vestfjord, Daugaard-Jensen,
Storstrommen, Petermann, 79North.
West: Rinks Isbrae (1957) and Melville Bay sector.

Rignot and Kanagaratnam, 2006

GRACE observations of mass change

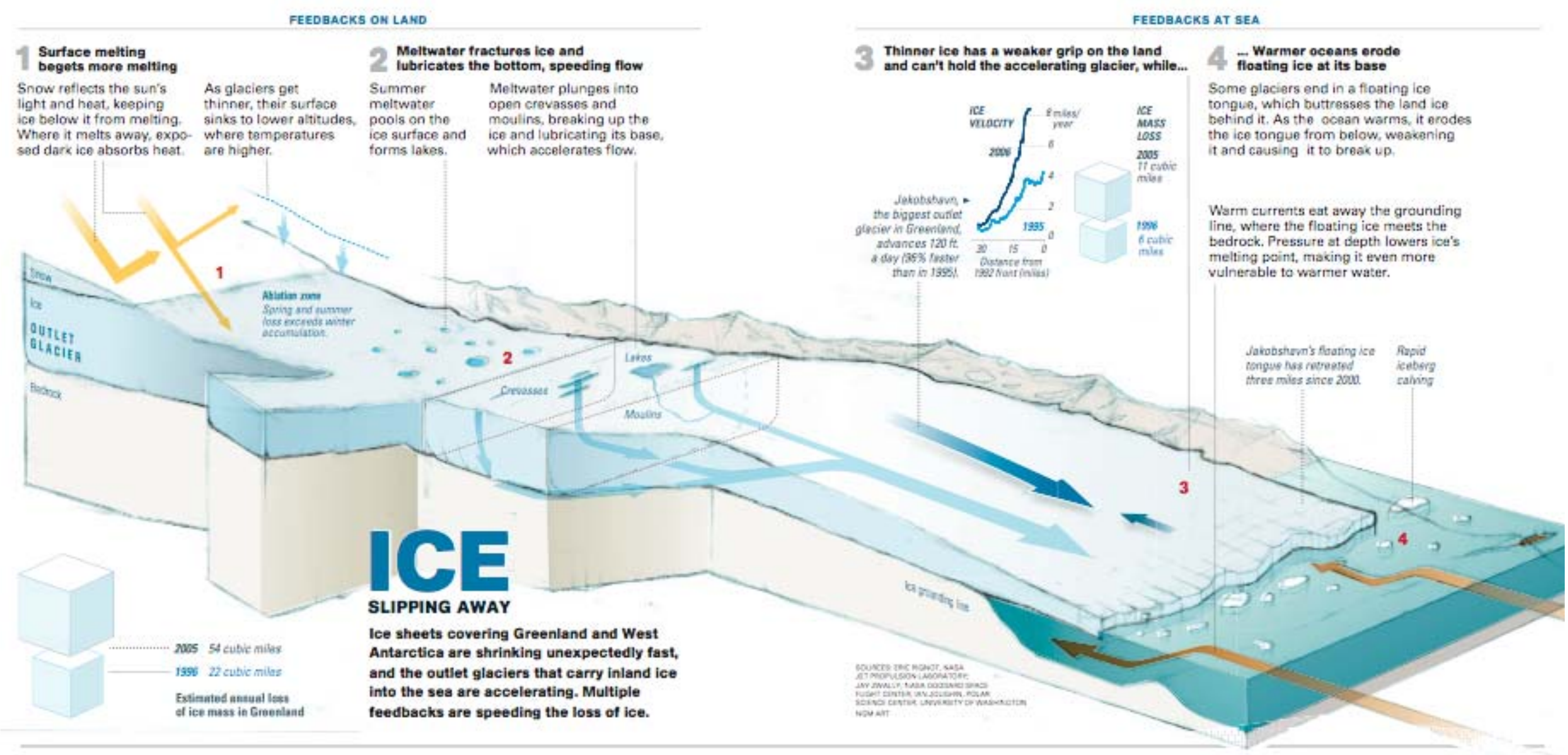


Velicogna and Wahr, 2006
Chen et al., 2006.

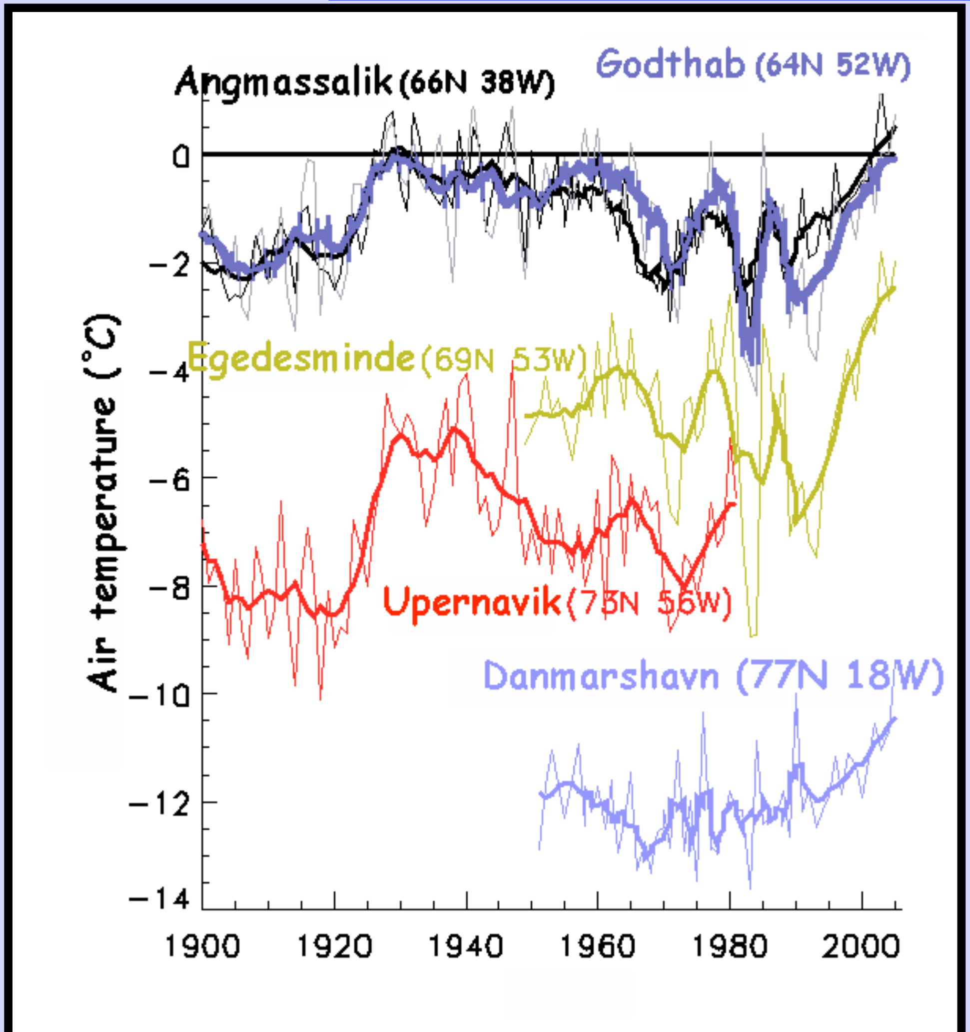


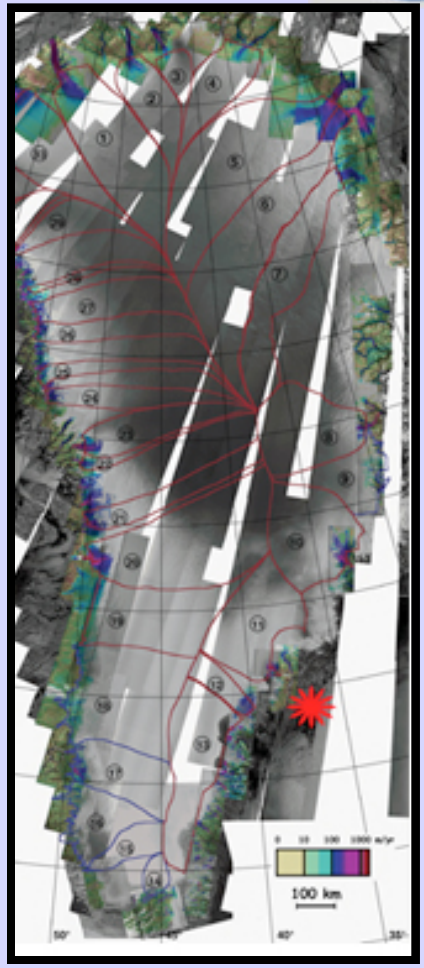
Driving factors?

Glacier ungrounding, melt water, bed below sea level, warm ocean.



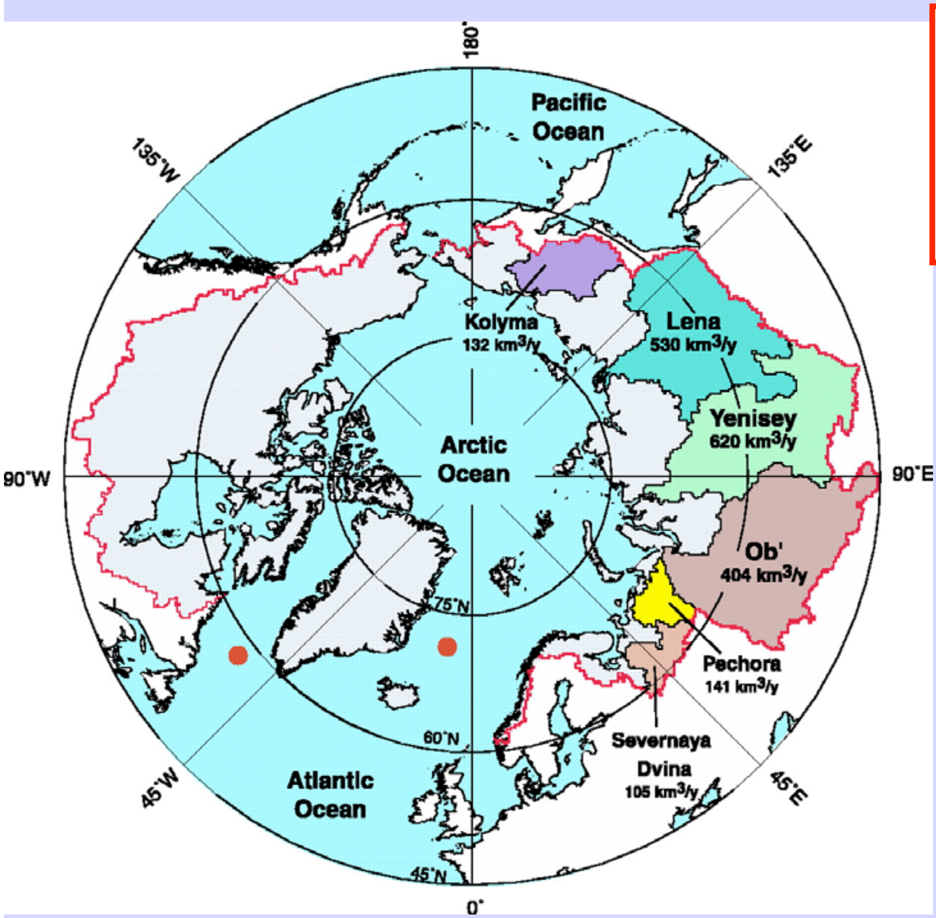
Climate Forcing





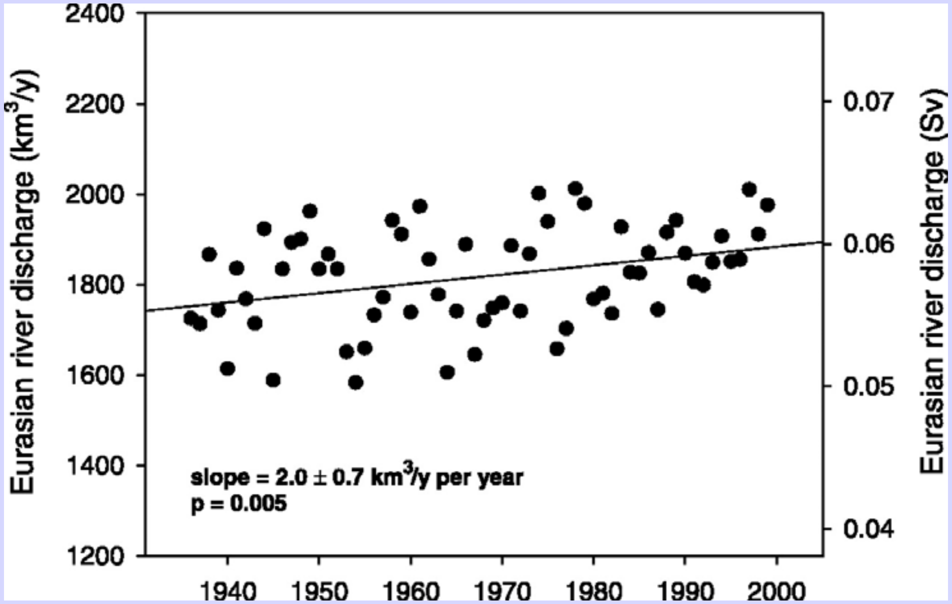
- 2-3°C increase in air temperature since 1980s (SW Greenland).
- Increase in ocean temperature not well constrained by observations.

Increase in Arctic river discharge



River discharge increased 2 km^3/yr since 1930s.
Total excess discharge ~ 128 km^3/yr.

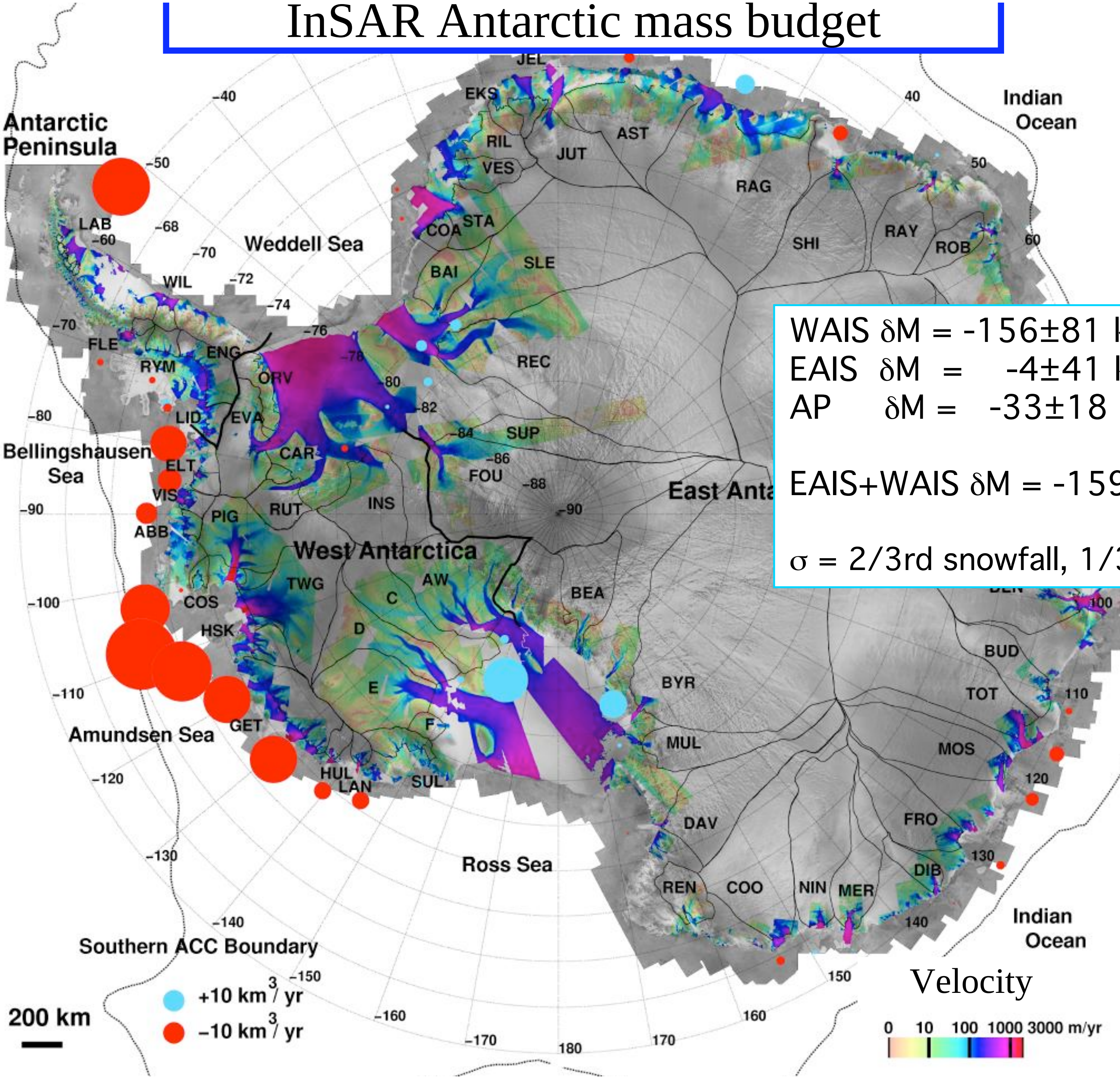
GrIS mass loss ~ 200km^3/yr.



Annual river discharge 1800 km^3/yr
Greenland accumulation 550 km^3/yr
Antarctica's accumulation 1800 km^3/yr .

(Peterson et al., 2002)

InSAR Antarctic mass budget



WAIS δM = -156±81 km^3/yr [-77, -226]

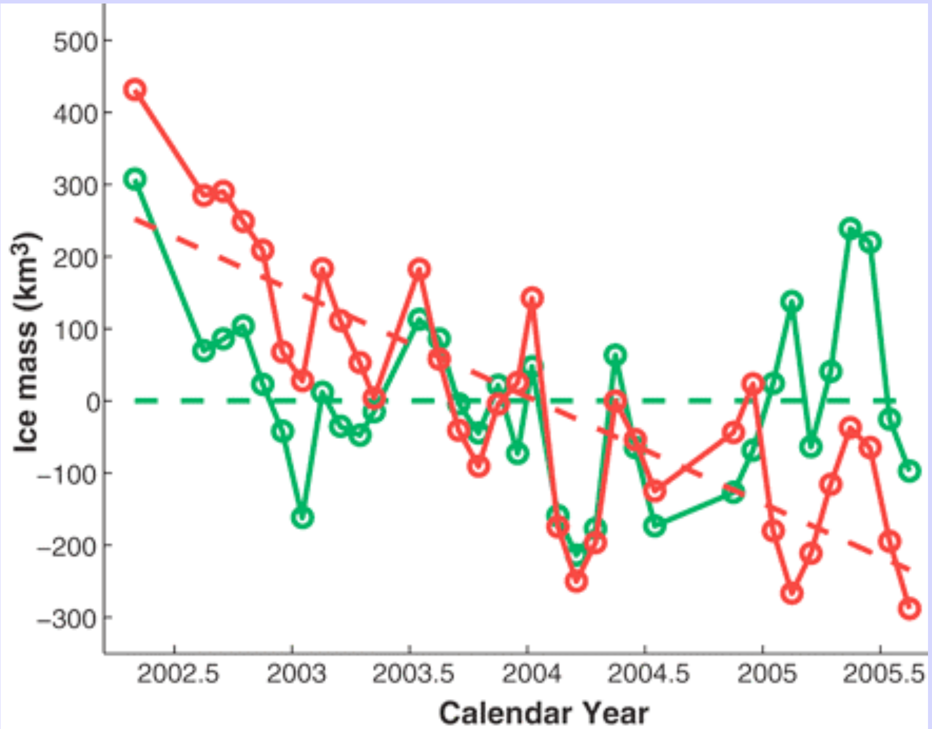
EAIS δM = -4±41 km^3/yr [-42, +33]

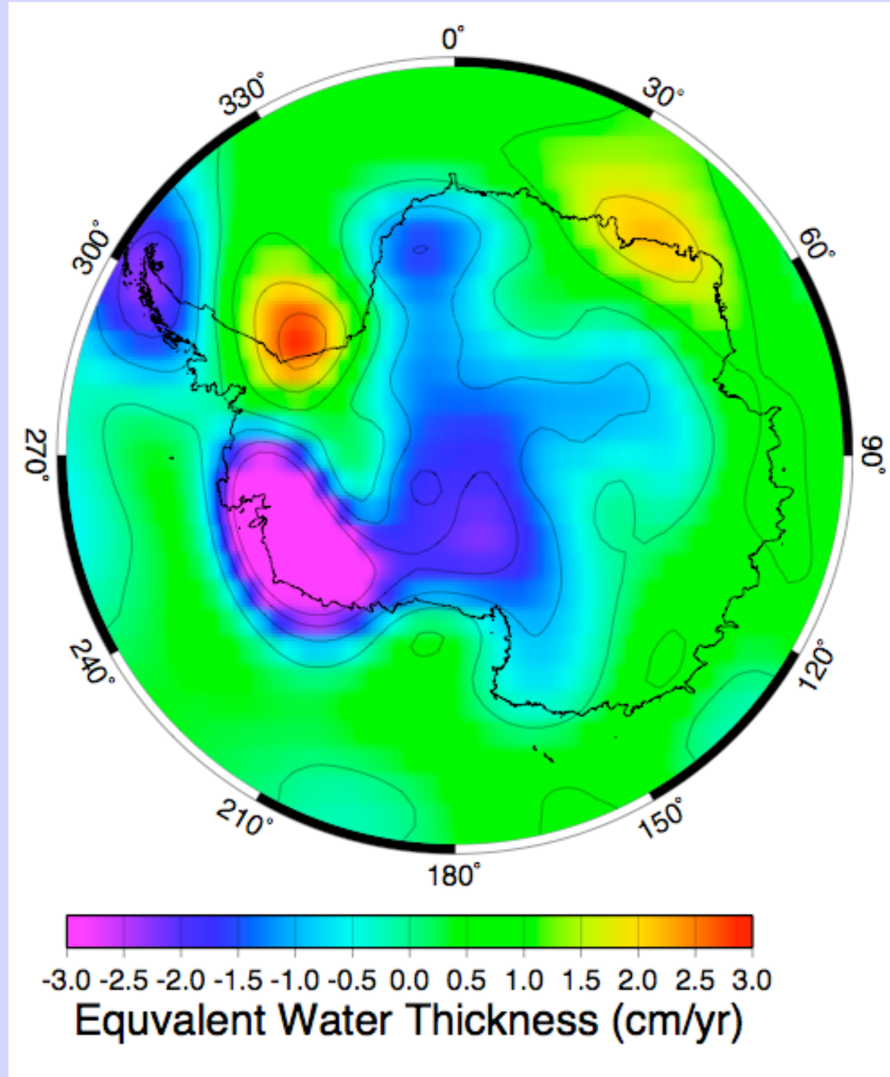
AP δM = -33±18 km^3/yr [-49, -20]

EAIS+WAIS δM = -159±77 km^3/yr

σ = 2/3rd snowfall, 1/3rd thickness.

Antarctica from GRACE



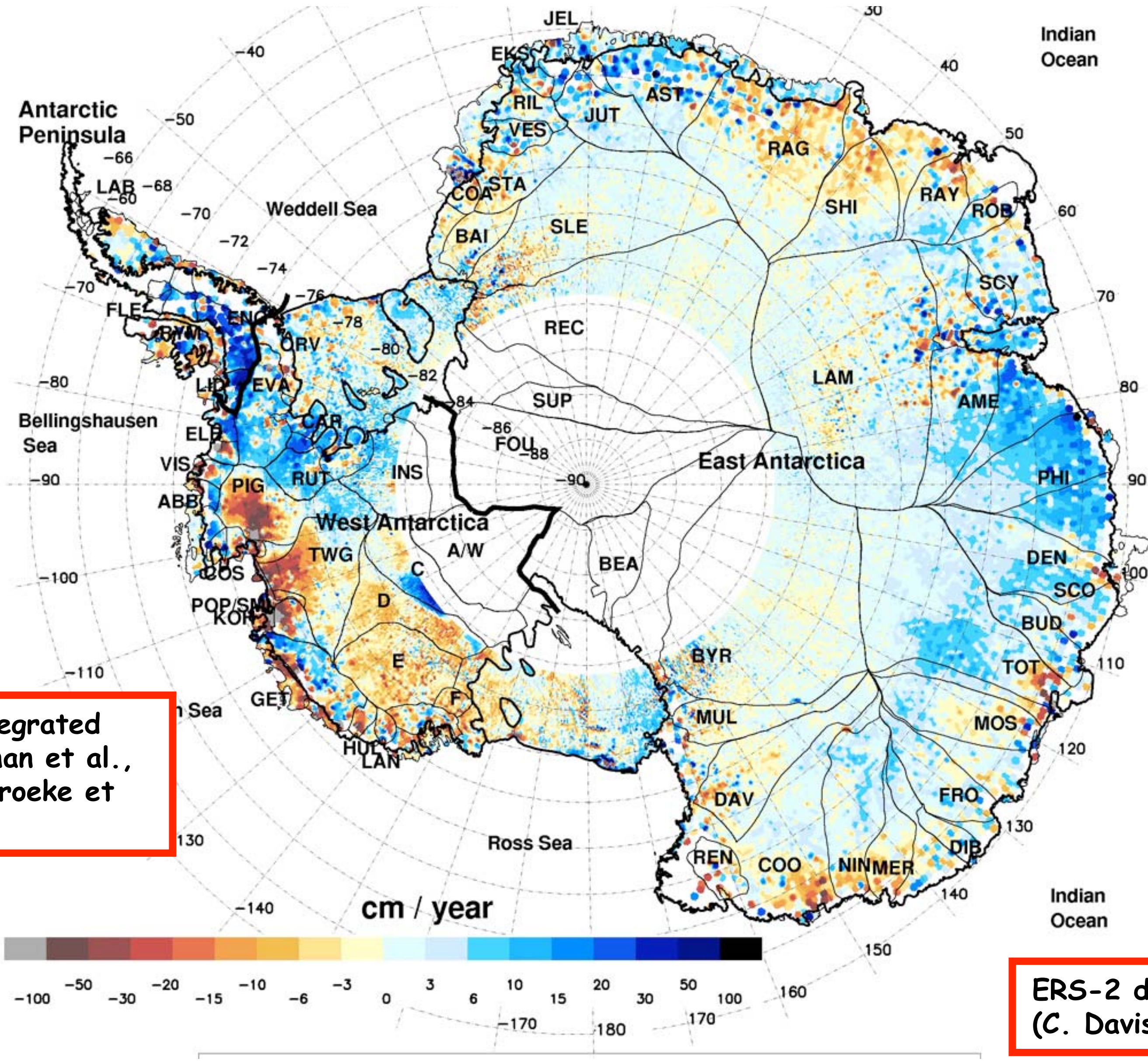


Mass loss mostly from WAnt (Velicogna and Wahr, 2006)

WAIS 148±21 km^3/yr
EAIS 0±56 km^3/yr
PGR 192±79 km^3/yr

Antarctic Elevation Changes

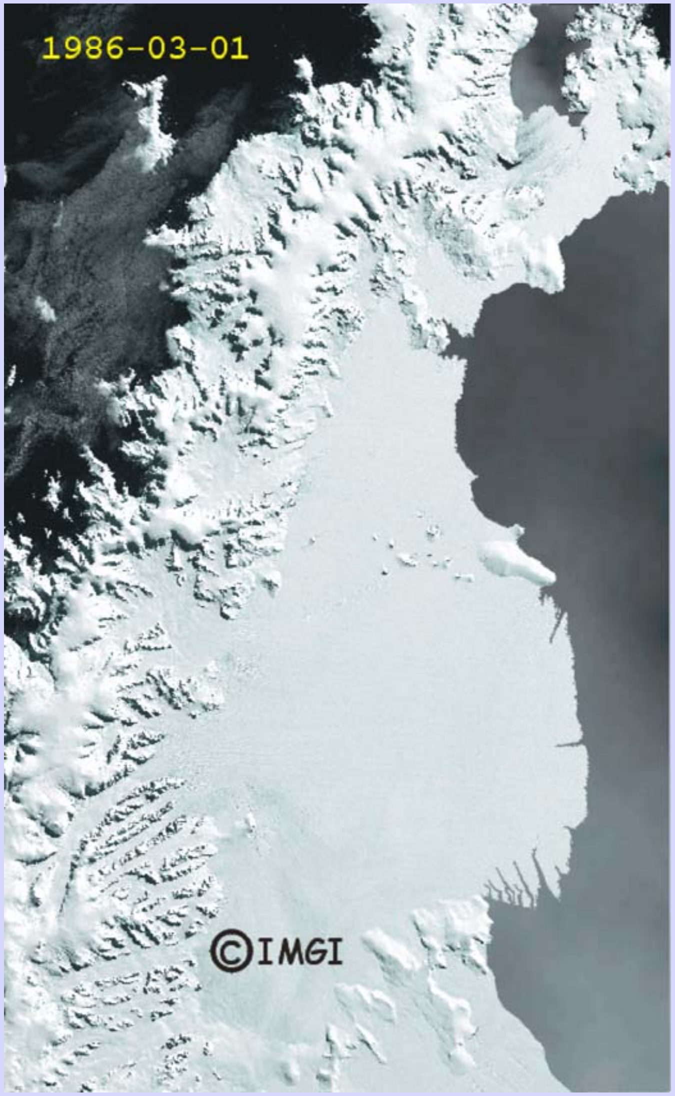
- Interior changes represents decadal variability.
- Pronounced areas of thinning at the coast, along glaciers

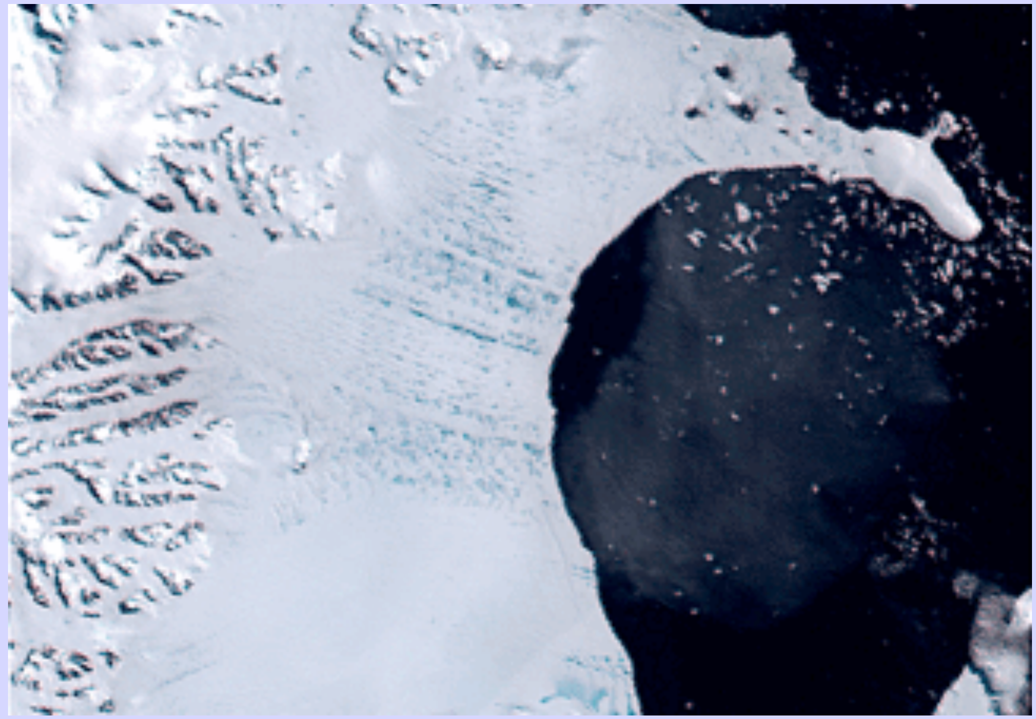


No change in integrated snowfall (Monaghan et al., 2006; van den Broeke et al., 2005)

ERS-2 dhdt 1992-2003 (C. Davis and Y. Li, 2005).

Larsen Ice Shelf Collapse

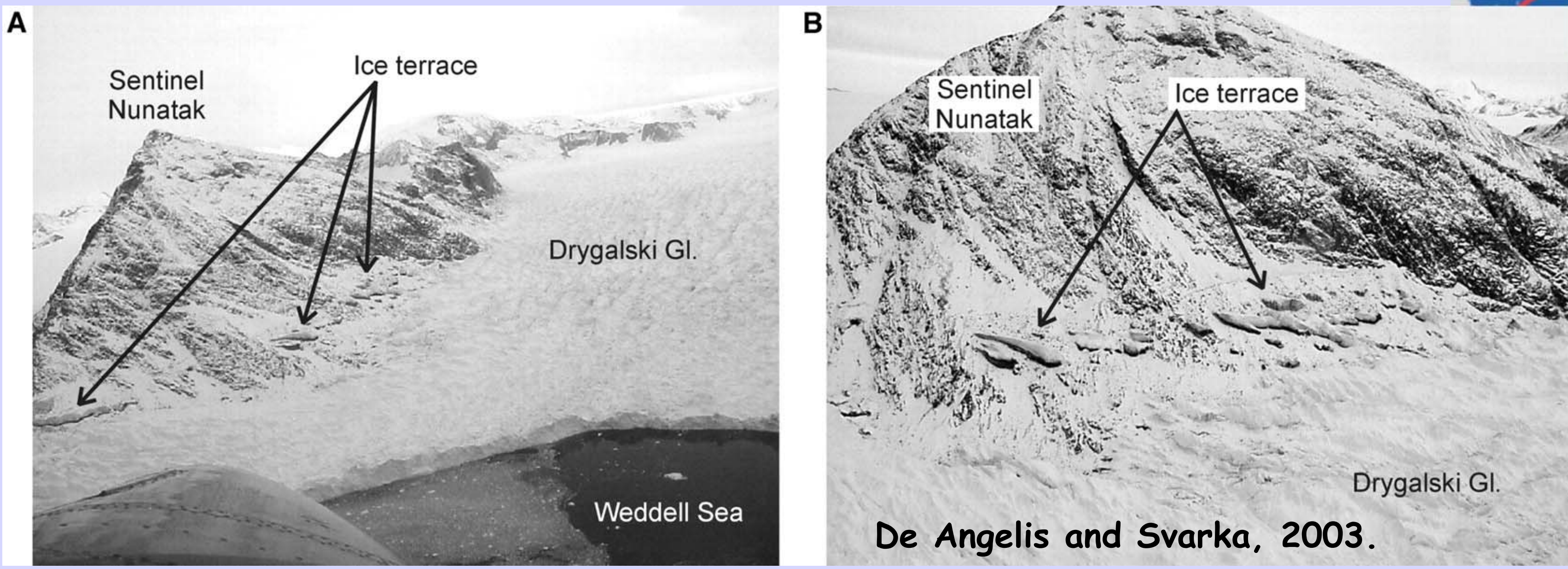




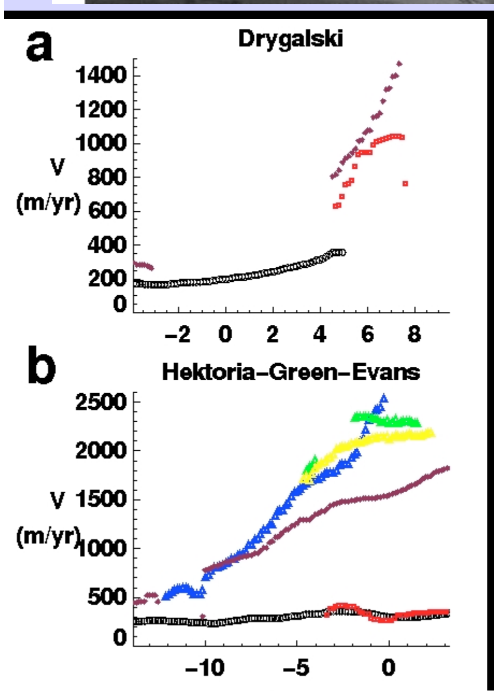
T. Scambos et al., 2002

Larsen B ice shelf collapsed in 3 weeks after 10,000 years of existence (Domack et al., 2005).

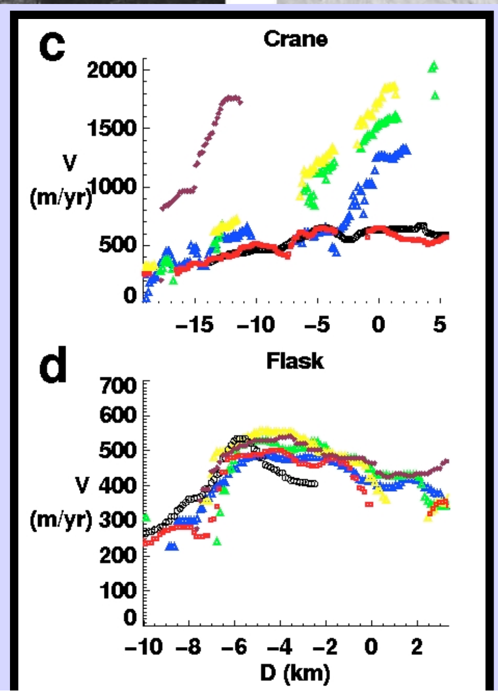
Ice Shelf collapse triggers glacier (large) speed up



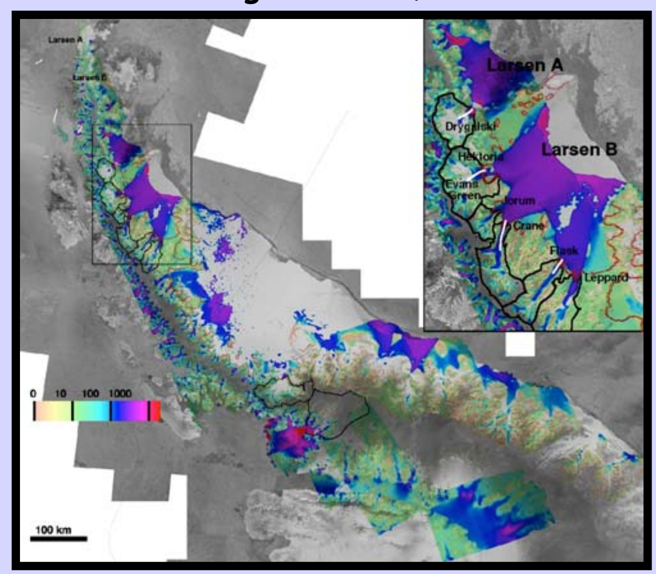
De Angelis and Svarka, 2003.



2005
2004
2003
2003
2000
1996

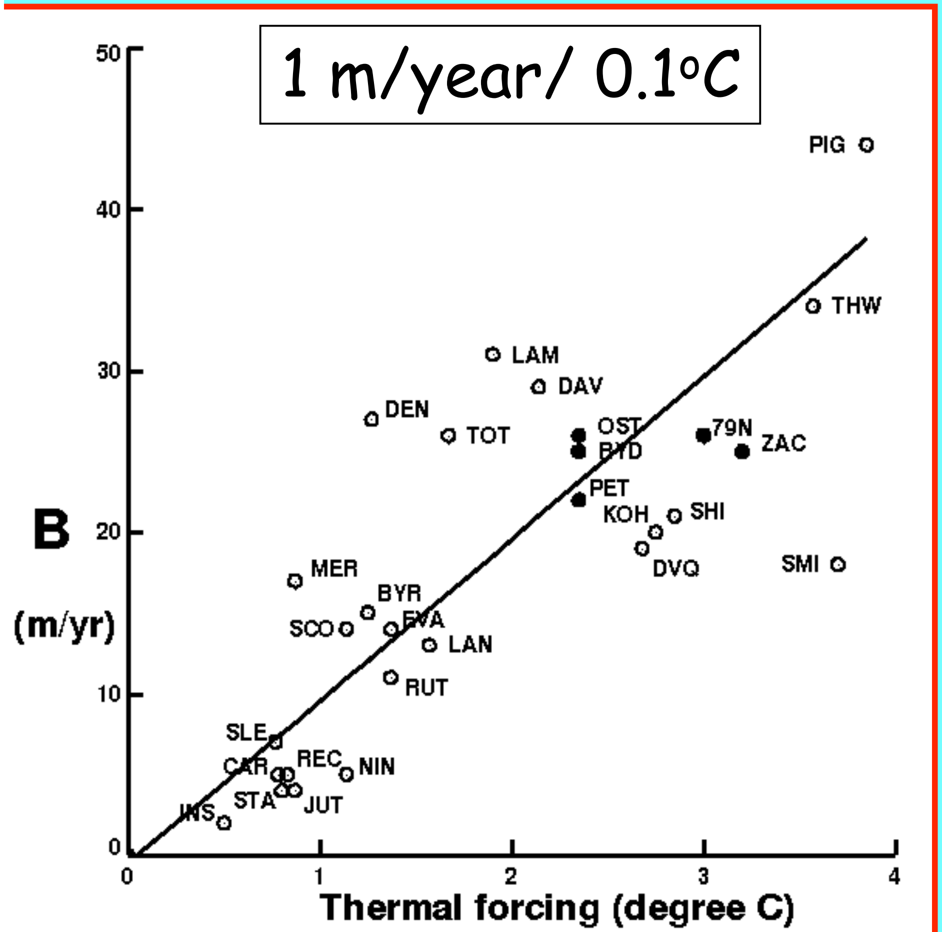


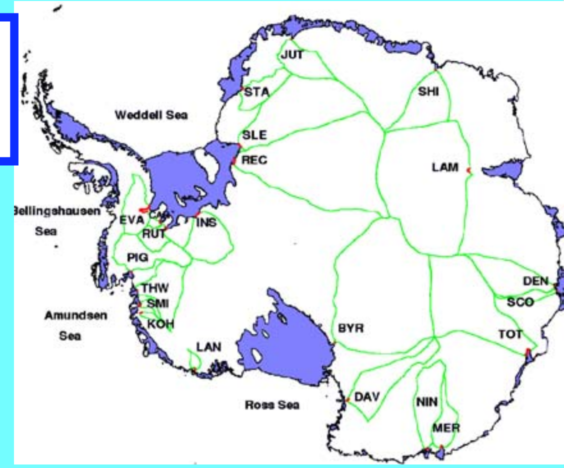
Rignot et al., 2004

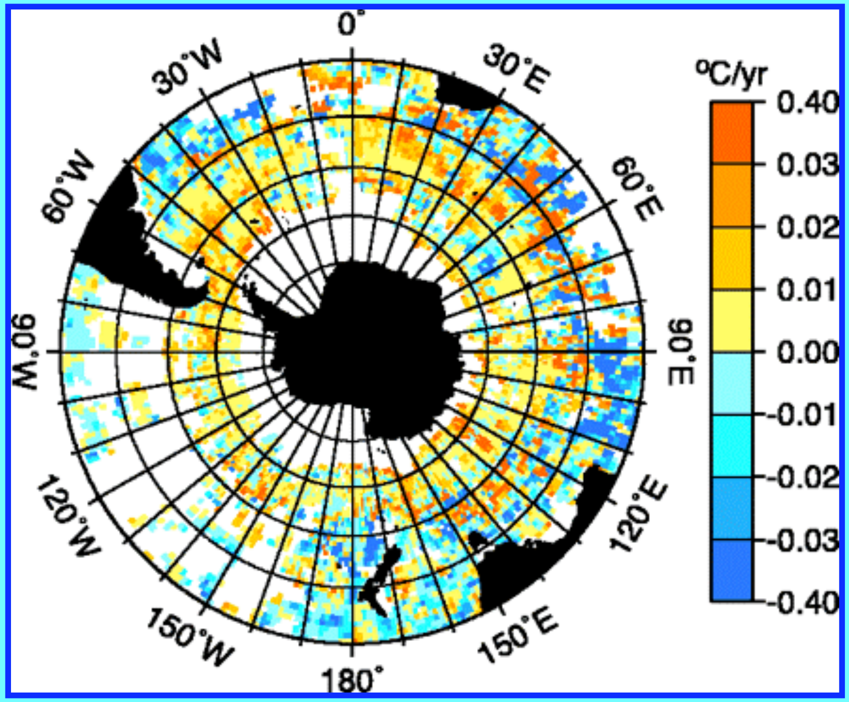


Antarctica's vulnerability to climate change

Basal melting vs thermal forcing







Mid-ocean temp. raised 0.17°C between 1950 and 1980 (Gille, 2002).

Rignot and Jacobs, 2002

What sensors do we need?

- InSAR for ice dynamics.
- Airborne laser altimetry and radar sounding missions for dhdt and glacier thickness.
- Gravity mission at high spatial resolution for mass change.
- Topography mission for volume change.

Only one of these will severely limit progress.
Most important observations at the coast .

- Others: AWS (climate), passive microwave (melt), etc.

What are the major uncertainties?

(besides listening to IPCC)

- How fast will Greenland change?

(Year 2100: 43 cm (IPCC), 1 meter (Rahmsdorf), or 3 meters (if we get there sooner, faster)).

- Can numerical ice sheet models become realistic?

(We do not have 30 years to find out).

- Poor observations of ice thickness (glaciers), coastal accumulation (Antarctica), fundamental mechanisms (iceberg calving, supraglacial, englacial and subglacial hydrology, basal sliding).

(IPY)

Conclusions

- GrIS is "melting" (200 km^3/yr), 2/3rd from ice dynamics, twice more than Arctic river excess discharge.
- Trillion $: How long before SLR is 3 m? 1,000 yrs? 100yrs?

- AntIS is "melting" (150 km^3/yr), mostly from ice dynamics in WAIS and Npen.
- Quadrillion $: When is a warmer ocean going to melt ice shelves and then air temperatures crack them apart?

- NASA Billion $: Remote sensing (InSARs + airborne surveys + GRACE follow on + topography mission), numerical ice sheet models, ocean temperature near grounding lines.